ROLE OF WATER JET DEVICES IN COMBAT SURGERY

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ROLE OF WATER JET DEVICES IN COMBAT SURGERY (U)

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The immediate management of combat wounds presents a variety of problems. These include time consuming debridement procedures as well as the ever present possibility of infection and suppuration. The accepted methods of debridement consist of scrubbing the wounds with one of a variety of disinfectants and washing it with the conventional bulb syringe. These methods are slow and may in some instances be less than totally effective. A series of studies were therefore begun at the United States Army Institute of Dental Research in 1966 to improve the then used methods of the debridement of the combat wounds. The purpose of this paper is to present findings from a series of studies which led to the development of new instruments and techniques for the debridement of combat wounds. These techniques and instruments are currently used in combat zones and have been adopted for use in selected military and civilian hospitals.

MATERIALS AND METHODS

Since water jet devices (WJD) are used in the oral hygiene procedures this modality was examined as a means for tissue debridement.[1] Two types of water jet devices delivering pulsating and nonpulsating jet streams were fabricated. They delivered up to 2400 ml of water per minute in from 1 to 8 jet streams at pressures which ranged up to 200 PSI. With these devices a series of experiments were conducted the purpose of which was to establish the following.

a. Effect of varied water pressure on soft tissue.

Beginning

b. Comparative efficiency of pulsating and nonpulsating water jets on tissues.

c. Comparison of pulsed lavage and conventional bulb syringe in wound debridement.

d. The effects of pulsating water lavage upon bacterial populations in contaminated wounds.

e. Effectiveness of pulsed water lavage and conventional bulb syringe in removing bacteria.

f. The effects of antibiotics on contaminated wounds when delivered by a pulsed water jet device.

g. The effect of antiseptic agents and pulsating jet lavage on contaminated wounds.

h. Effect of pulsed pressure lavage on bacteremia.

i. Pulsating water jet for debridement of radioactive wounds.

j. Effect of water lavage on removal of tissue fragments from crush wounds.

k. Pulsating water jet devices in debridement of combat wounds.

Each of these experiments and the findings will be described separately.

Effect of Varied Water Pressure on the Oral Mucosa[2,3]

In order to determine the effect of varied water pressure on oral tissues of different densities, the oral mucosa of 60 rats and four dogs were subjected to continuous water jets at 70, 100, 150 and 200 PSI. Tongue, mucobuccal fold and the attached gingiva were selected to represent sites of varying density. It was demonstrated that the tissue change depends on the density and mobility of the mucosa as well as on the force of the water jet. Whereas very high pressures (100-200 PSI) produce hemorrhages in the tongue, pressures of up to 200 PSI applied to the attached gingiva in rats and dogs caused only transitory changes. It was suggested by this study that continuous water jets at 70 PSI applied for 30 seconds at one site on the gingiva should produce no deleterious effects.

Since the water jet at 70 PSI was found to be safe for use on gingival tissues (dense keratinized area) in order to determine the optimal water pressure for use in the mobile nonkeratinized areas of the mucosa, the ventral surface of the rat tongue was exposed to 30 second exposures of pulsating water jet at 75, 50 and 25 PSI in 45 animals. It was observed that whereas 70 to 75 PSI produces clinical evidence of ulceration and hemorrhage, water jet at 50 PSI produced no evidence of clinical pathology. Microscopically the lavaged area showed minimal reversible changes.

The ventral surface of the rat tongue is covered by extremely thin mucosa, it is mobile and is very easily subjected to ulceration. Even in such an area water jets at 50 PSI caused little damage.

On the basis of these studies therefore it was determined that water jets of pressures from 50 to 70 PSI could be safely used in the human oral mucosal tissues with safety.

Comparative Efficiency of Pulsating and Nonpulsating Water Jets on Tissues[1]

When pulsating and nonpulsating water jets at comparable pressures (100 PSI) and jet diameter were used on the dense oral mucosa (attached gingiva) of 48 rats, no clinical difference was observed. On the tongue, however, the formation of hematoma was far more common with the continuous stream. Histologically the number and degree of subepithelial hemorrhages was more prevalent with the continuous stream than with the pulsating jet of identical force. In order to determine the reason why comparable water pressures as pulsating and nonpulsating jets would produce clinically different tissue responses the effect of water jets on tissues was examined by high speed cinematography. It was observed that the continuous water jet stream hit the soft tissues and kept the area of impact in a continuous "compression phase" (CP). The pulsating water jet on the other hand had a "compression phase" and an "interpulse decompression phase" (IDP) during which the impacted tissues were decompressed. These observations during the debridement of orofacial wounds revealed that the IDP permitted the foreign debris to escape from the wound but the continuous CP of the nonpulsed jets kept the wounded tissues compressed and interfered with a maximal escape of the contaminants.

As a result of these studies therefore the pulsating water jet devices were selected for further study.

The optimal pressures at which they were used ranged from 50 to 70 PSI.

Comparison of Pulsed Water Lavage and Conventional Bulb Syringe in Wound Debridement[4]

In order to determine the effectiveness of pulsed water lavage as compared to the conventional bulb syringe, preauricular facial wounds were created in 60 rats and measured amounts of silver filings were introduced and manipulated into the cut tissues. Wounds were then lavaged with pulsed water jets at 25, 50 and 70 PSI (± 5 PSI) and with a conventional bulb syringe. The amount of water used in irrigation was collected, the silver filings recovered, dried and weighed. A comparison of the four groups revealed that the pulsed water jets at any of the pressures used were superior to the conventional methods. The latter left about three times more debris in the wound than the pulsed water lavage.

The Effects of Pulsating Water Lavage Upon Bacterial Populations in Contaminated Wounds[5]

Wounds were made in the preauricular area of 56 rats and these were infected with 0.02 ml of moist soil which contained 1.5×10^7 cells of Proteus mirabilis and Klebsiella pneumoniae in equal concentrations. Thirty minutes later the wounds were treated by one of the following four methods. They were left open, closed with sutures, lavaged with a pulsating jet at 70 PSI for 30 seconds and left open, or after the pulsating lavage they were closed primarily. This study showed the water lavage not only was effective in removing dirt and debris but also removed bacteria from the wounds. The lavaged wounds yielded negative cultures up to nine days earlier than the unlavaged wounds and those which were closed primarily gave the optimal results. It was suggested therefore that lavage followed by primary closure was the best of the four methods used in the management of the orofacial wounds.

Effectiveness of Pulsed Water Lavage and Conventional Bulb Syringe in Removing Bacteria[6]

In this experiment the effectiveness of pulsating water lavage and conventional bulb syringe in preventing infection of contaminated wounds was studied. The standard wounds (which were used also in other experiments) were created in 380 rats as follows: After the animals

were anesthetized with sodium pentobarbital, the left preauricular area of each rat was shaved. A vertical incision was made in the masseter muscle, 1.5 cm long and extending to the lateral surface of the mandibular ramus. Each wound was contaminated with 0.03 ml of moist soil which contained equal concentration of Staphylococcus aureus, Proteus mirabilis, Pseudomonas aeruginosa, and Klebsiella pneumoniae. These bacteria were used because they are most commonly isolated from infected combat wounds in Vietnam. The total number of bacteria in each soil sample was approximately 3×10^7. The infected soil was allowed to remain in the wound for 30 minutes.

Wounds of animals in Group I (experimental) were lavaged with a pulsating water (tap water) jet at 70 PSI for 30 seconds, while wounds of the animals in Group II (control) were lavaged with conventional bulb syringe. Approximately 350 ml of water was used for each wound with either of the methods. After lavage all wounds were closed with silk sutures. Forty animals from each group were killed on the 2nd, 4th, 6th and 8th postoperative days and 30 animals from each group on the 10th day. The wound edges were separated and a sterile cotton-tipped applicator was inserted into the base of the wound and streaked on the following culture media: blood agar, mannitol salt agar, salmonella-shigella agar, and pseudomonas isolation agar.

The results of this experiment showed that the use of water jet lavage significantly reduces the incidence of wound infection. This method is superior to the conventional irrigation with a bulb syringe. During the ten day period the experimental group showed 106 animals with negative cultures for K. pneumoniae, 121 for P. aeruginosa, 85 for P. mirabilis, and 54 for S. aureus. The control group by contrast showed only 25, 11, 10 and 9 negative cultures respectively. The total number of negative cultures in the experimental group during the ten day period was 366 in contrast to only 55 in the control group. This is reduction of about seven times and has been shown statistically to be highly significant.

During this experiment 37 animals in the water jet lavage group but only 2 in the bulb lavage group had wounds that became sterile. Furthermore, the sterile wounds occurred earlier in the experimental group than in the control group.

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The Effects of Antibiotics on Contaminated Wounds when Delivered by a Pulsed Water Jet Device.[1,7,8]

Since the effectiveness of water pressure lavage had been clearly established, the possibility of further improvement of this modality was investigated. For this purpose three experiments were conducted to determine whether the addition of antibiotics to the water lavage would enhance the antibacterial effect of this modality.

1. Effect of streptomycin in pulsed water lavage on bacteria.
2. Effect of penicillin and streptomycin in pulsed water lavage on bacteria.
3. Effect of vancomycin, streptomycin and tetracycline in pulsed water lavage on bacteria.

The standard wounds were created and contaminated as described above, except that in the first experiment S. aureus, P. mirabilis and Escherichia coli were used.

1. Effect of Streptomycin and Pulsed Water Lavage on Bacteria[1]

Thirty-six animals were divided into two groups and the control animals of Group I were lavaged for 30 seconds with a pulsating water jet at 70 PSI while the experimental group was lavaged with water which contained 2.85 mgm/ml of streptomycin. Animals were killed at 2, 3, 4, 5, 8 and 12 days postoperatively, and cultures were obtained from each wound. Whereas 31 positive cultures were obtained in the control group only 14 were obtained in the experimental. Streptomycin lavage was particularly effective against Proteus mirabilis and Escherichia coli but was relatively ineffective against the Staphylococcus aureus. Histologic analysis revealed that wounds which were lavaged with streptomycin showed less inflammation than the control.

2. Effect of Penicillin and Streptomycin in Pulsed Water Lavage on Bacteria[7]

Two hundred and twenty albino rats were used in this experiment. The wounds of the experimental group were lavaged with a pulsating jet and a solution containing 250 units/ml of penicillin and 1.42 mg/ml of streptomycin. Animals in the control group were treated in the same manner as those in the experimental group, except that 350 ml of saline solution instead of antibiotic solution was used. In the experimental group during the eight day

period K. pneumoniae was isolated from eleven wounds, P. aeruginosa from sixteen, P. mirabilis from twelve, and S. aureus from twenty two, while in the saline pressure lavage group the same microorganisms were isolated from seventy-nine, seventy-six, seventy, and fifty-seven wounds, respectively. Thus, the total number of positive cultures in the antibiotic lavage group was sixty-one in contrast to 282 in the control group. This is a reduction of about 4.5 times. What appears to be even more important is, that during the same period, out of 110 animals in each group, wounds of seventy-nine animals in the antibiotic group were sterile as compared to twenty-five in the control group.

During the eight day experiment there were 379 negative cultures out of the 440 in the experimental group but only 158 out of 440 in the control group. The 66.7 to 95.0 per cent decrease in the frequency of isolation of introduced bacterial species from wounds on the first and second postoperative days appears to be particularly important. Such initial reduction should allow earlier healing, less destruction of tissue, less morbidity, and less scar formation. Since the emergence of many resistant strains of gram-negative bacteria to streptomycin, other antibiotics incorporated into the water jet lavage may give even better results. However, even the strains that are referred to as "resistant" may be affected if an antibiotic is applied locally in high concentration.

The significant reduction of wound infection as shown in this report was obtained by the use of only one lavage of 30 seconds duration. It is possible that the effectiveness of this method may be further increased by the parenteral administration of the same antibiotic (s).

3. Effect of Vancomycin, Streptomycin and Tetracycline in Pulsed Water Lavage on Bacteria[8]

Two hundred and twenty-five albino rats where divided into three groups of 75 each and 30 minutes after wound contamination, the wounds were treated as follows:

Group I (control)	lavage with saline.
Group II	lavage with 1.42 mg/ml solution of tetracycline.
Group III	lavage with solution of 1.42 mg/ml of vancomycin and 1.42 mg/ml of streptomycin.

The results showed that pulsating saline lavage had a similar effect on the four organisms used. Although on the fourth day there was a smaller number of wounds infected with P. mirabilis and S. aureus than with the two other types of bacteria, the differences were not significant. On the sixth day, there was 34-40 per cent reduction in the number of positive cultures, but on the eighth day this percentage increased to 83.4 per cent. In the saline group throughout the 10 day period, there were 39 wounds infected with K. pneumoniae, 45 with P. aeruginosa, 35 with P. mirabilis, and 36 with S. aureus.

The lavage of wounds with tetracycline solution affected the four organisms to a different degree. The effectiveness of this antibiotic in providing protection against infection with K. pneumoniae was very high. No wounds in this group revealed positive cultures of K. pneumoniae. This reduction was statistically significant.

Tetracycline was also effective against S. aureus. The highest number of positive cultures of this organism was only three on the fourth and sixth days, only two on the first day, and one on the remaining days. Such reduction when compared with the control group, is statistically significant on the second (P 0.005), fourth and sixth days, (P 0.05). Although the number of wounds infected with P. mirabilis was lower in this group than in the control group, statistical analysis revealed that the reduction was significant (P 0.05) only on the second day postoperatively. P. aeruginosa was not affected by tetracycline. The number of positive cultures of P. aeruginosa in this group is almost identical with the number in the control group. The reduction in the total number of positive cultures of K. pneumoniae (0), P. mirabilis (17) and S. aureus (10) during the 10 day period in the tetracycline group, when compared with the number of positive cultures of the same organisms in the control group is significant (P 0.005).

The solution of vancomycin and streptomycin was shown to be very effective in providing protection against development of wound infection with the four microorganisms used. The reduction in the incidence of wound infection during the first six days was significant when compared with the control group. The pressure lavage with vancomycin-streptomycin solution completely eliminated K. pneumoniae from wounds of 75 animals. Out of 75 wounds, P. mirabilis was isolated from only one wound, S. aureus from only four, and P. aeruginosa from only nine wounds. Such effectiveness in prevention of wound infection, when compared with the control group, is highly

significant (P 0.005). The fact that P. aeruginosa was susceptible to vancomycin-streptomycin jet lavage is of special importance. Furthermore, the elimination or reduction of all types of bacteria from the wounds as early as the second day allows earlier healing, less destruction of tissue, and less scar formation. More than 50 per cent of wounds lavaged with vancomycin and tetracycline were sterile on the second day, while in the saline and tetracycline group none of the wounds were free of bacteria. The number of sterile wounds in the vancomycin-streptomycin group was also much higher on the second through eighth days than in the two other groups. These differences were statistically significant.

The Effect of Antiseptic Agents and Pulsating Jet Lavage on Contaminated Wounds[9]

Standard preauricular wounds were created on 480 albino rats. After contamination as in other studies (above) each wound was irrigated with approximately 350 ml of one of the following solutions:

Group I (control)	water
Group II	undiluted povidone-iodine solution (Betadine(R)).
Group III	20 per cent solution of phisohex (R).
Group IV	0.1 per cent solution of benzalkonium chloride (Zephiran).

The results showed that during the 10 day period the total number of wounds infected with K. pneumoniae was 82 in Group I, 92 in Group II, 84 in Group III, 78 in Group IV. These differences are statistically not significant. P. aeruginosa was isolated from 95, 103, 99 and 99 wounds in the respective groups. The differences between the groups are not significant.

The numbers of positive cultures of P. mirabilis were 85, 87, 84 and 84 in respective groups. These differences are not significant.

The total number of wounds infected with S. aureus in H_2O povidone-iodine and PHisoHex groups also did not differ significantly. However, there were only 26 wounds during the 10 day period which were found to be infected with S. aureus in the benzalkonium chloride group. This reduction in the incidence of infection in this group as compared to 92, 85 and 95 in the first 3 groups respec-

tively is statistically significant.

The total number of sterile wounds during 10 days was 14, 9, 10 and 15 for Groups I, II, III, and IV respectively but these differences are not statistically significant.

Comparison of this data with the number of sterile wounds obtained following the lavage with antibiotics clearly indicates that the latter method is much more effective than pressure irrigation of contaminated wounds with solutions of the antiseptic agents tested.

Effect of Pulsed Pressure Lavage on Bacteremia[10]

In the above described experiments of the effect of pulsating jet lavage in the treatment of contaminated wounds, the irrigating solutions were delivered to the tissue at a high pressure. Therefore, there was a possibility that bacteria in the wound could be forced into the tissue and enter the blood stream. Such a possibility was tested on 75 albino rats. After the standard wounding, contamination and water pressure lavage, 5 ml samples of blood were obtained 2, 5, 10, 20 and 30 minutes after lavage. Fifteen rats were used for each collection time. Bacteremia due to K. pneumoniae was present in only one animal from each sampling group at 10 20 and 30 minutes after lavage. No other bacteria introduced into the wounds were isolated from blood at any time. Although there were 11 positive cultures, the subcultures on blood agar plates and subsequent Gram staining have shown the organisms to be other than those used for wound contamination. Therefore, these 11 positive cultures were considered to be a result of contamination.

The result of this experiment indicates that the incidence of bacteremia following the pressure lavage of contaminated wounds in the rat is very low even when antibiotics are not utilized. It is recognized, however, that further studies of possible bacteremia in man following pressure lavage are needed.

Pulsating Water Jet for Debridement of Radioactive Wounds[11]

This investigation was undertaken to determine if water jet devices could more effectively decontaminate radioactivity from wounds than the conventional methods of bulb syringe irrigation. It is based on 62 adult albino rats in which a preauricular wound was created and

contaminated with a slurry containing radioactive $Zn^{65}Cl_2$. The animals were divided into 4 groups. Group I was used to establish the accuracy of the method used in the detection of radioactivity. Groups II, III and IV were decontaminated with a single stream pulsating water jet device, conventional bulb syringe and a multiple stream water jet device respectively. It was found that:

a. The single stream water jet device was about 2.5 times more effective than the conventional bulb syringe in removing the radioactive material. Since it took only one third the time taken by the latter method, it would appear to be about 7.5 times more efficient.

b. The multiple pulsating water jets are more effective than single jet devices.

c. It is concluded from this study that pulsating water jet devices are effective means for the decontamination and debridement of soft tissue wounds.

Effect of Water Lavage on Removal of Tissue Fragments from Crush Wounds[12]

One of the main objects of wound debridement is to separate viable tissue from dead and dying tissue fragments. At the present time most debridement is done by surgically cutting out and scraping away areas of necrotic or questionable tissue. The object of this study was to see the quantitative effect of pulsed water jet lavage on wound debridement with the idea of eventually determining the optimal conditions so that water lavage could be used to perform wound debridement in a faster and less traumatic manner.

It is shown that on 30 minute crush wounds, pulsed water lavage at 35 g/mm^2 is 18 times as effective as the bulb syringe, and at 49 g/mm^2 is 40 times more effective than the bulb syringe. Even after 2 days the pulsed water lavage at 49 g/mm^2 is 17 times as effective as the bulb syringe. The water jet devices and medium and high settings (50-70 PSI) are therefore recommended for wound debridement. This selection of medium or high pressure settings is dependent upon the friability and vulnerability of the target tissues.

Pulsating Water Jet Devices in Debridement of Combat Wounds[13]

As a result of the animal experiments, it was concluded that the use of PWJ lavage would be of benefit in

the management of combat wounds. For this reason, pulsed water jet lavage was effectively employed on 25 patients in Vietnam.

In using the PWJ in combat injuries, either a mixture of penicillin and streptomycin (10 million units and two gm per 1000 ml respectively) or 2.5 gm per 1000 ml of tetracycline was added to the lavage water. In addition, the corresponding drug was administered systemically. The usual procedure for PWJ debridement consisted of gently cleaning the wound area with Betadine and sponge, followed by the use of PWJ containing one of the antibiotics and then rinsing the area with saline. If the dirt persisted, the procedure was repeated.

In addition to the facial injuries, eight cases involving wounds of the extremities were lavaged with the PWJ. Postoperative complications were not observed in any of the patients, and healing clinically was judged to occur faster than expected. The orofacial wounds were closed primarily, but delayed closures were accomplished in the wounds of the extremities, and the orthopedic surgeons responsible for these cases were of the impression that they could accomplish closure one to two days sooner than with the conventional methods (excision and saline irrigation).

Pulsating water jet lavage was found most effective in the following types of cases in Vietnam: (a) all orofacial wounds containing soil and clothing fragments or vegetative contaminants; and (b) blast injuries, especially where fine particles of foreign bodies have been forced into the tissues. Use of PWJ was not only more effective, but it was far less irritating and produced less edema than the conventional scrubbing with a brush. Instruments which yield multiple pulsating water jets are currently being used in military hospitals[14] (Fig. 1).

SUMMARY

A series of studies were conducted at the United States Army Institute of Dental Research, a laboratory of the Medical Research and Development Command the purpose of which was to develop an efficient method for the debridement of combat wounds. These experiments led to the fabrication and utilization of a new multi-jet pulsating device which is currently used for effective and rapid debridement of combat and noncombat wounds. The experiments described in this report reveal the following.

1. Pulsating water jet (PWJ) is more effective in tissue debridement than a jet of continuous stream.

2. Pulsating water jets of 50-70 PSI are effective and safe to use on wounded soft tissues.

3. PWJ are more effective in tissue debridement than the conventional methods (bulb syringe).

4. When antibiotics are used with the PWJ this modality markedly reduces the incidence of infections in contaminated wounds.

5. Antiseptic agents are not as effective in the management of the contaminated wounds as the antibiotics.

6. Use of the PWJ does not cause bacteremia.

7. PWJ are effective means of removing tissue tags from crushed contaminated wounds.

8. PWJ are effective in removing radioactive material from wounds.

9. As a result of these studies special instruments were designed and pulsating water jets with antibiotics are currently being used in the management of combat and noncombat wounds.

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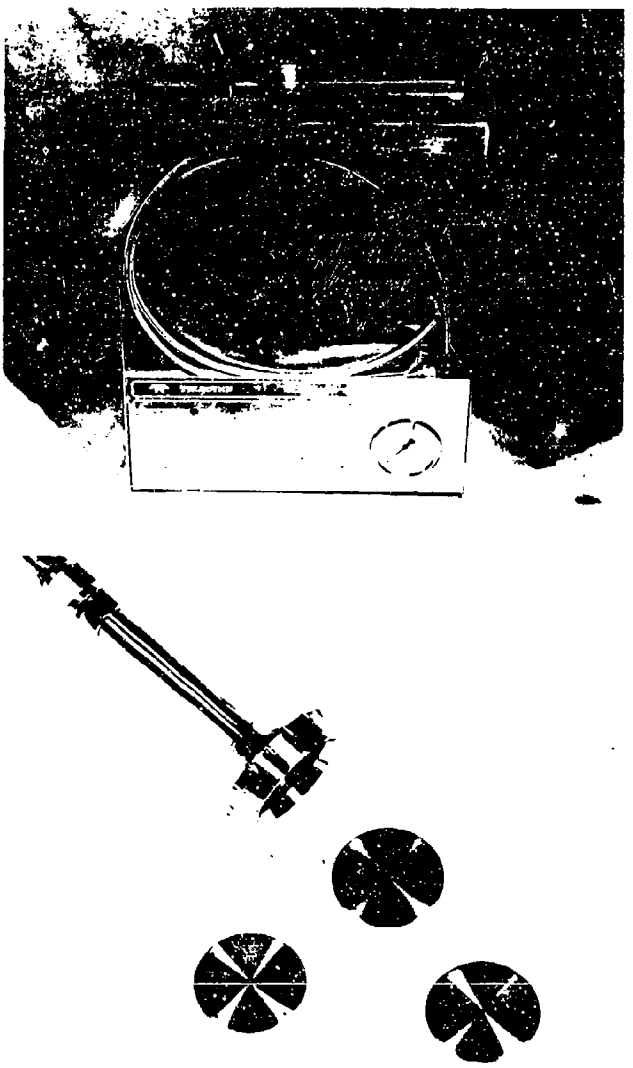

FIG. 1

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